TITLE

CONTROL METHOD AND SYSTEM FOR MOTOR

BACKGROUND OF THE INVENTION

1. Field of the invention

The present invention relates to a control method and system for a motor, more particularly, to a control method and system using a micro-programming & memory controller for a motor.

2. Description of the Related Art

Fig. 1 shows a conventional PI-PWM (Proportion Integration-Pulse Width Modulation) current control system 11 for a motor 10. The conventional PI-PWM current control system 11 comprises: a first difference operator 12, a PI controller 14, a second difference operator 15, a PWM comparator 16 and an inverter 18. The control system 11 receives three phase reference currents 20 to the first difference operator 12, and detects three phase actual currents 22 from a motor 10. The first difference operator 12 calculates three phase difference currents between the three phase reference currents 20 and three phase actual currents 22.

The three phase difference currents are amplified by the PI controller 14 to obtain three phase control voltages. The second difference operator 15 calculates difference voltages between the three phase control voltages and three phase triangle-wave signals 24. The PWM comparator 16 receives the three phase difference voltages and outputs three phase switch signals to the inverter 18. According to the three phase switch signals, the inverter 18 outputs three phase input voltages to the motor 10 and controls the motor 10.

However, the conventional PI-PWM current control system 11 has

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the current phase-lag problem. Referring to Figs. 2A, 2B, 3A, 3B and 3C, they show the comparison between the three phase actual currents and the three phase reference currents, according to the conventional PI-PWM current control system. Fig. 2A shows A phase reference current $I_{a1,\ refer}$. Fig. 2B shows A phase actual current $I_{a1,actual}$. Fig. 3A shows a comparison between A phase reference current $I_{a1,refer}$ and A phase actual current $I_{a1,actual}$. Fig. 3B shows a comparison between B phase reference current $I_{b1,refer}$ and B phase actual current $I_{b1,actual}$. Fig. 3C shows a comparison between C phase reference current $I_{c1,refer}$ and C phase actual current $I_{c1,actual}$. As shown in Figs. 2A, 2B, 3A, 3B and 3C, the current phase-lag problem exists between the three phase reference currents $I_{a1,refer}$, $I_{b1,refer}$, $I_{c1,refer}$ and three phase actual currents $I_{a1,actual}$, $I_{b1,actual}$, $I_{c1,actual}$.

Besides, when a software is utilized to perform the operation of the PI controller 14, the conventional PI-PWM current control system 11 has the high noise problem. Figs. 4A, 4B, 5A, 5B and 5C show the comparison between the three phase actual currents and the three phase reference currents, according to the conventional PI-PWM current control system 11 using a software to perform the PI controller 14. Fig. 4A shows A phase reference current $I_{a2,\ refer}$, Fig. 4B shows A phase actual current $I_{a2,actual}$, Fig. 5A shows a comparison between A phase reference current $I_{a2,refer}$ and A phase actual current $I_{a2,actual}$, Fig. 5B shows a comparison between B phase reference current $I_{b2,refer}$ and B phase actual current $I_{b2,actual}$, Fig. 5C shows a comparison between C phase reference current $I_{c2,refer}$ and C phase actual current $I_{c2,actual}$. As shown in Figs. 4A, 4B, 5A, 5B and 5C, the three phase actual currents $I_{a1,actual}$, $I_{b1,actual}$, $I_{c1,actual}$ have the high noise problem.

Therefore, it is necessary to provide an innovative and progressive control method and system to solve the above problem.

SUMMARY OF THE INVENTION

One objective of the present invention is to provide a control method

and system for a motor. The control method comprises the steps of: (a) determining a motor parameter; (b) providing a d-axis reference current and a q-axis reference current; (c) detecting actual currents of the motor and converting to a d-axis actual current and a q-axis actual current; (d) calculating a d-axis counter electromotive force and a q-axis counter electromotive force at a sample period according to the motor parameter, the d-axis actual current and the q-axis actual current at the sample period, the d-axis actual current and the q-axis actual current at a last sample period, and a d-axis voltage and a q-axis voltage at the last sample period; and (e) calculating a d-axis voltage and a q-axis voltage at the sample period according to the motor parameter, the d-axis actual current and the q-axis actual current at the sample period, the d-axis reference current and the q-axis reference current at a next sample period, the d-axis counter electromotive force and the q-axis counter electromotive force calculated at the sample period.

According to the control method of the invention, the d-axis voltage and the q-axis voltage are calculated and converted to three phase control voltages. The three phase control voltages are processed to control the motor. The control method of the invention not only preserves the merit of constant switching frequency of the conventional PI-PWM control system, but also can eliminate the motor current phase-lag problem of the conventional PI-PWM control system. Also the control method of the invention will have the following characteristics and economic advantages such as high accuracy, fast response, low cost and robustness etc.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows a block diagram of a conventional PI-PWM current control system for a motor.

Fig. 2A shows A phase reference current $I_{a1,\,refer}$ waveform.

Fig. 2B shows A phase actual current $I_{a1,actual}$ waveform, according to

the conventional PI-PWM current control system.

Figs. 3A to 3C show comparison waveforms between the three phase reference currents and the three phase actual current, according to the conventional PI-PWM current control system.

Fig. 4A shows A phase reference current $I_{a2, refer}$ waveform.

Fig. 4B shows A phase actual current $I_{a2,actual}$ waveform, according to the conventional PI-PWM current control system using a software to perform the operation of PI controller.

Figs. 5A to 5C show comparison waveforms between the three phase reference currents and the three phase actual current, according to the conventional PI-PWM current control system using a software to perform the operation of PI controller.

Fig. 6A shows a block diagram of a control system for a motor, according to the invention.

Fig. 6B shows a block diagram of a micro-programming & memory controller, according to the invention.

Fig. 7 shows a flow chart of a control method for a motor, according to the invention.

Fig. 8A shows A phase reference current $I_{a3, refer}$ waveform.

Fig. 8B shows A phase actual current $I_{a3,actual}$ waveform, according to the control system of the invention using a correct leakage inductance.

Figs. 9A to 9C show comparison waveforms between the three phase reference currents and the three phase actual current, according to the control system of the invention using a correct leakage inductance.

Fig. 10A shows A phase reference current $I_{a4, refer}$ waveform.

Fig. 10B shows A phase actual current $I_{a4,actual}$ waveform, according to the control system of the invention using an excessive leakage inductance.

Figs. 11A to 11C show comparison waveforms between the three phase reference currents and the three phase actual current, according to the control system of the invention using an excessive leakage inductance.

Fig. 12A shows A phase reference current $I_{a5, refer}$ waveform.

Fig. 12B shows A phase actual current $I_{a5,actual}$ waveform, according to the control system of the invention using 'an inadequate leakage inductance.

Figs. 13A to 13C show comparison waveforms between the three phase reference currents and the three phase actual current, according to the control system of the invention using an inadequate leakage inductance.

Fig. 14A to 14C show three phase actual currents, according to the control system of the invention using a software to tune the leakage inductance.

Fig. 14D shows the change of the leakage inductance, according to the control system of the invention using a software to tune the leakage inductance.

DETAILED DESCRIPTION OF THE INVENTION

The control method of the invention can be utilized to control an AC motor, more particularly to control an induction motor so that three phase actual currents are equal to three phase reference currents. In the embodiment, the induction motor is taken as an example to describe the operation of the control method and system of the invention. However, the control method and system of the invention are not limited to control the induction motor, the other AC motor and DC motor can be controlled by

the control method and system of the invention.

Firstly, the induction motor dynamic equations on the synchronous rotating d-q frame are shown as follows Equation (1).

$$\frac{d}{dt}\begin{bmatrix} i_{ds} \\ i_{qs} \\ \lambda_{dr} \\ \lambda_{qr} \end{bmatrix} = \begin{bmatrix} -\left(\frac{r_s}{L_\sigma}+\frac{r_r'\cdot L_M'^2}{L_\sigma\cdot L_{rr}'^2}\right) & \omega_e & \frac{r_r'\cdot L_M}{L_\sigma\cdot L_{rr}'^2} & \omega_r\frac{L_M}{L_\sigma L_{rr}'} \\ -\omega_e & -\left(\frac{r_s}{L_\sigma}+\frac{r_r'\cdot L_M^2}{L_\sigma\cdot L_{rr}'^2}\right) & -\omega_r\frac{L_M}{L_\sigma\cdot L_{rr}'} & \frac{r_r'\cdot L_M}{L_\sigma L_{rr}'^2} \\ r_r'\frac{L_M}{L_{rr}'} & 0 & -\frac{r_r'}{L_{rr}'} & (\omega_e-\omega_r) \\ 0 & r_r'\frac{L_M}{L_{rr}'} & -(\omega_e-\omega_r) & -\frac{r_r'}{L_{rr}'} \end{bmatrix}\cdot\begin{bmatrix} i_{ds} \\ i_{qs} \\ \lambda_{dr} \\ \lambda_{qr} \end{bmatrix}+\begin{bmatrix} \frac{1}{L_\sigma} & 0 \\ 0 & \frac{1}{L_\sigma} \\ 0 & 0 \\ 0 & 0 \end{bmatrix}\cdot\begin{bmatrix} V_{ds} \\ V_{qs} \end{bmatrix} \quad (1)$$

wherein L_σ is defined as a leakage induction.

$L_\sigma = \left(1-\frac{L_M^2}{L_{ss}L_{rr}}\right)L_{ss} = \frac{L_{ss}L_{rr}-L_M^2}{L_{rr}}$ =leakage inductance

Equation (1) is re-arranged, and a d-axis voltage V_{ds} and a q-axis voltage V_{qs} are obtained as follows.

$$\begin{cases} V_{ds} = L_\sigma\frac{di_{ds}}{dt} - L_\sigma\omega_e i_{qs} - \omega_r\frac{L_M}{L_{rr}'}\lambda_{qr} + \left(r_s + r_r'\frac{L_M^2}{L_{rr}'^2}\right)\cdot i_{ds} - r_r'\frac{L_M}{L_{rr}'^2}\lambda_{dr} & (2) \\ V_{qs} = L_\sigma\frac{di_{qs}}{dt} + L_\sigma\omega_e i_{ds} + \omega_r\frac{L_M}{L_{rr}'}\lambda_{dr} + \left(r_s + r_r'\frac{L_M^2}{L_{rr}'^2}\right)\cdot i_{qs} - r_r'\frac{L_M}{L_{rr}'^2}\lambda_{qr} & (3) \end{cases}$$

A d-axis counter electromotive force E_{ds} and a q-axis counter electromotive force E_{qs} are defined as follows.

$$\begin{cases} E_{ds} = -\omega_r\frac{L_M}{L_{rr}'}\lambda_{qr} + \left(r_s + r_r'\frac{L_M^2}{L_{rr}'^2}\right)\cdot i_{ds} - r_r\frac{L_M}{L_{rr}'^2}\lambda_{dr} & (4) \\ E_{qs} = +\omega_r\frac{L_M}{L_{rr}'}\lambda_{dr} + \left(r_s + r_r'\frac{L_M^2}{L_{rr}'^2}\right)\cdot i_{qs} - r_r\frac{L_M}{L_{rr}'^2}\lambda_{qr} & (5) \end{cases}$$

Therefore, Equation (2) and (3) can be simplified as follows.

$$V_{ds} = L_\sigma \frac{di_{ds}}{dt} - L_\sigma \omega_e i_{qs} + E_{ds} \quad (6)$$

$$V_{qs} = L_\sigma \frac{di_{qs}}{dt} + L_\sigma \omega_e i_{ds} + E_{qs} \quad (7)$$

Wherein di_{ds}/dt and di_{qs}/dt can be calculated by a d-axis reference current $i_{ds,ref}$, a q-axis reference current $i_{qs,ref}$, a d-axis actual current $i_{ds,actual}$ and a q-axis actual current $i_{qs,\ actual}$ as follows.

$$\frac{di_{ds}}{dt} = \frac{i_{ds,ref}(t+T_s) - i_{ds,actual}(t)}{T_s} = \frac{i_{ds2,error}}{T_s} \quad (8)$$

$$\frac{di_{qs}}{dt} = \frac{i_{qs,ref}(t+T_s) - i_{qs,actual}(t)}{T_s} = \frac{i_{qs2,error}}{T_s} \quad (9)$$

Wherein T_s is a sample time, and T_s =0.2ms. The $i_{ds,actual}$ (t) means a $i_{ds,actual}$ value at a sample period. The $i_{qs,actual}$ (t) means a $i_{qs,actual}$ value at a sample period. The $i_{ds,\ ref}$ (t+T_s) means a $i_{ds,ref}$ value at a next sample period. The $i_{qs,ref}$ (t+T_s) means a $i_{qs,ref}$ value at a next sample period. Therefore, di_{ds}/dt and di_{qs}/dt can be calculated easily by Equations (8) and (9).

The d-axis counter electromotive force E_{ds} and the q-axis counter electromotive force E_{qs} can be derived from Equations (6) and (7) as follows.

$$\begin{cases} E_{ds} = V_{ds} - L_\sigma \frac{di_{ds}}{dt} + L_\sigma \omega_e i_{qs} & (10) \\ E_{qs} = V_{qs} - L_\sigma \frac{di_{qs}}{dt} - L_\sigma \omega_e i_{ds} & (11) \end{cases}$$

Wherein di_{ds}/dt and di_{qs}/dt can be calculated by the d-axis actual current $i_{ds,\ actual}$ and the q-axis actual current $i_{qs,\ actual}$ as follows.

$$\begin{cases} \dfrac{di_{ds}}{dt} = \dfrac{i_{ds,actual}(t) - i_{ds,actual}(t - T_s)}{T_s} = \dfrac{i_{ds1,error}}{T_s} & (12) \\ \dfrac{di_{qs}}{dt} = \dfrac{i_{qs,actual}(t) - i_{qs,actual}(t - T_s)}{T_s} = \dfrac{i_{qs1,error}}{T_s} & (13) \end{cases}$$

Wherein T_s is a sample time, and T_s =0.2ms. The $i_{ds,actual}$ (t) means a $i_{ds,actual}$ value at a sample period. The $i_{qs,actual}$ (t) means a $i_{qs,actual}$ value at a sample period. The $i_{ds,\ actual}$ (t-T_s) means a $i_{ds,actual}$ value at a last sample period. The $i_{qs,actual}$ (t-T_s) means a $i_{qs,actual}$ value at a last sample period. Therefore, di_{ds}/dt and di_{qs}/dt in Equations (10) and (11) can be calculated easily by Equations (12) and (13).

Therefore, the d-axis voltage V_{ds} and the q-axis voltage V_{qs} can be calculated by Equations (6) to (13) according to the leakage inductance, the d-axis reference current $i_{ds,ref}$, the q-axis reference current $i_{qs,ref}$, the d-axis actual current $i_{ds,actual}$ and the q-axis actual current $i_{qs,actual}$.

Referring to Fig. 6A, Fig. 6B and Fig. 7, the control system 60 comprises: a micro-programming & memory controller 61, a PWM comparator 62 and a switch-mode inverter 63. The micro-programming & memory controller 61 comprises: an input means 611, a detecting means 612, a first calculating means 613, a second calculating means 614, a converting means 615 and a third calculating means 616. The input means 611 is used for receiving a motor parameter, a d-axis reference current $i_{ds,ref}$ and a q-axis reference current $i_{qs,ref}$. The motor parameter can be a leakage inductance L_σ , and the expression is $L_\sigma = \left(1 - \frac{L_M^2}{L_{ss}L_{rr}}\right)L_{ss} = \frac{L_{ss}L_{rr} - L_M^2}{L_{rr}}$. The leakage inductance L_σ can be a constant. As shown in step 701 of Fig. 7, the motor parameter is determined.

The input means 611 can receive three phase reference currents 601,

then the three phase reference current are converted to the d-axis reference current $i_{ds,ref}$ and the q-axis reference current $i_{qs,ref}$, as shown in step 702 of Fig. 7. Then, it is easy to obtained the d-axis reference current $i_{ds,ref}(t+T_s)$ and the q-axis reference current $i_{qs,ref}(t+T_s)$ at a next period in Equations (8) and (9).

The detecting means 612 is used for detecting three phase actual currents 602 from a motor 64 and converting the three phase actual currents to a d-axis actual current $i_{ds,actual}$ and a q-axis actual current $i_{qs,actual}$, as shown in step 703 of Fig. 7. At a sample time, the d-axis actual current $i_{ds,actual}(t)$ and the q-axis actual current $i_{qs,actual}(t)$ can be obtained in real-time, and at a last sample time $(t-T_s)$ the values of the d-axis actual current $i_{ds,actual}(t-T_s)$ and the q-axis actual current $i_{qs,actual}(t-T_s)$ are stored in a memory.

Therefore, the di_{ds}/dt and di_{qs}/dt in Equations (12) and (13) can be calculated. The $i_{ds,actual}(t)$ is the $i_{ds,actual}$ value at a sample period, the $i_{qs,actual}(t)$ is the $i_{qs,actual}$ value at a sample period, and the $i_{ds,\ actual}(t-T_s)$ is the stored $i_{ds,actual}$ value at a last sample period. The $i_{qs,actual}(t-T_s)$ is the stored $i_{qs,actual}$ value at a last sample period.

The first calculating means 613 is utilized to calculate a d-axis counter electromotive force E_{ds} and a q-axis counter electromotive force E_{qs} at a sample period according to the motor parameter L_σ , the d-axis actual current $i_{ds,actual}(t)$ and the q-axis actual current $i_{qs,actual}(t)$ at the sample period, the d-axis actual current $i_{ds,actual}(t-T_s)$ and the q-axis actual current $i_{qs,\ actual}(t-T_s)$ at a last sample period, and a d-axis voltage V_{ds} and a q-axis voltage V_{qs} at the last sample period. Therefore, the d-axis counter electromotive force E_{ds} and the q-axis counter electromotive force E_{qs} are calculated by Equations (10) and (11). The method for calculating the d-axis counter electromotive force E_{ds} and the q-axis counter electromotive force E_{qs} is shown in step 704 of Fig. 7.

The second calculating means 614 is used for calculating a d-axis voltage V_{ds} and a q-axis voltage V_{qs} at the sample period according to the motor parameter L_σ, the d-axis actual current $i_{ds,actual}$ (t) and the q-axis actual current $i_{qs,actual}$ (t) at the sample period, the d-axis reference current $i_{ds,ref}$ ($t+T_s$) and the q-axis reference current $i_{qs,ref}$ ($t+T_s$) at a next sample period, the d-axis counter electromotive force E_{ds} and the q-axis counter electromotive force E_{qs} at the sample period calculated by the first calculating means 612. Therefore, the d-axis voltage V_{ds} and the q-axis voltage V_{qs} are calculated by Equations (6) and (7). The method for calculating the d-axis voltage V_{ds} and the q-axis voltage V_{qs} is shown in step 705 of Fig. 7. The d-axis voltage V_{ds} and the q-axis voltage V_{qs} can be used to control the motor 64.

At the first sample period, the d-axis counter electromotive force E_{ds} and the q-axis counter electromotive force E_{qs} are equal to zero. Then, the d-axis voltage V_{ds} and the q-axis voltage V_{qs} can be calculated by Equations (6) and (7) at the first sample period using $E_{ds}=0$ and $E_{qs}=0$. At the second sample period, the d-axis counter electromotive force E_{ds} and the q-axis counter electromotive force E_{qs} can be calculated by Equations (10) and (11) using the d-axis voltage V_{ds} and the q-axis voltage V_{qs} at the first sample period. Then, the d-axis voltage V_{ds} and the q-axis voltage V_{qs} can be calculated by Equations (6) and (7) at the second sample period using the d-axis counter electromotive force E_{ds} and the q-axis counter electromotive force E_{qs} calculated at the second sample period. The above steps are repeated to calculate the d-axis voltage V_{ds} and the q-axis voltage V_{qs} every sample period so as to control the motor 64 of Fig. 6A.

The converting means 615 is used for converting the d-axis voltage V_{ds} and the q-axis voltage V_{qs} to three phase voltage V_{as}, V_{bs}, V_{cs}, as shown in step 706 of Fig. 7. The three phase voltage are converted by the third calculating means 616 to obtain three phase control voltage $V_{a,control}$, $V_{b,control}$ and $V_{c,control}$, as shown in step 707 of Fig. 7, according to the three

phase voltages V_{as} ,V_{bs} , V_{cs} , a peak voltage of a comparing voltage V_{Tri_p} and a DC voltage of the switch-mode inverter V_d as follows.

$$\begin{cases} V_{a,control} = (V_{as} * V_{Tri\_P})/(1/2 * V_d) & (14) \\ V_{b,control} = (V_{bs} * V_{Tri\_P})/(1/2 * V_d) & (15) \\ V_{c,control} = (V_{cs} * V_{Tri\_P})/(1/2 * V_d) & (16) \end{cases}$$

The three phase control voltages are compared with a comparing voltage 603 by the PWM comparator 62, as shown in step 708 of Fig. 7. The comparing voltage 603 is a triangle wave voltage signal. After the PWM comparator 62, three phase switching signals are obtained to input and control the switch-mode inverter 63, as shown in step 709 of Fig. 7. The switch-mode inverter 63 outputs three phase input voltages to the motor 64, as shown in step 710 of Fig. 7.

Therefore, the three phase input voltages of motor can be calculated by the control method and the control system, according to the invention. The motor 64 can be controlled by the three phase input voltages so as to perform the objective of the three phase actual currents being equal to the three phase reference current.

Figs. 8A, 8B, 9A, 9B and 9C show the comparison between the three phase actual currents and the three phase reference currents, according to the control system 60 and the control method of the invention. Fig. 8A shows A phase reference current $I_{a3,\ refer}$, Fig. 8B shows A phase actual current $I_{a3,actual}$, Fig. 9A shows a comparison between A phase reference current $I_{a3,refer}$ and A phase actual current $I_{a3,actual}$, Fig. 9B shows a comparison between B phase reference current $I_{b3,refer}$ and B phase actual current $I_{b3,actual}$, and Fig. 9C shows a comparison between C phase reference current $I_{c3,refer}$ and C phase actual current $I_{c3,actual}$. Figs. 8A, 8B, 9A, 9B and 9C are obtained by utilizing the Matlab software to perform the operation of the control system and using a correct leakage inductance. As shown in Figs. 9A, 9B and 9C, the three phase actual currents $I_{a3,actual}$, $I_{b3,actual}$, $I_{c3,actual}$ are almost equal to the three phase reference currents $I_{a3,refer}$

, $I_{b3,refer}$, $I_{c3,refer}$, respectively. Therefore, the control system can solve the current phase-lag problem in the conventional PI-PWM current control system.

To prove the robustness of the control system according to the invention, the Matlab software is also utilized to perform the operation of the control system using an excessive value of leakage induction and an inadequate value of leakage induction.

Figs. 10A, 10B, 11A, 11B and 11C show the comparison between the three phase actual currents and the three phase reference currents, according to the control system 60 and the control method of the invention and using an excessive value of leakage induction 1.5 L_σ . Fig. 10A shows A phase reference current $I_{a4,refer}$, Fig. 10B shows A phase actual current $I_{a4,actual}$, Fig. 11A shows a comparison between A phase reference current $I_{a4,refer}$ and A phase actual current $I_{a4,actual}$, Fig. 11B shows a comparison between B phase reference current $I_{b4,refer}$ and B phase actual current $I_{b4,actual}$, and Fig. 11C shows a comparison between C phase reference current $I_{c4,refer}$ and C phase actual current $I_{c4,actual}$. As shown in Figs. 11A, 11B and 11C, even using the excessive leakage induction 1.5 L_σ , three phase actual currents $I_{a4,actual}$, $I_{b4,actual}$, $I_{c4,actual}$ are still almost equal to the three phase reference currents $I_{a4,refer}$, $I_{b4,refer}$, $I_{c4,refer}$, respectively.

Figs. 12A, 12B, 13A, 13B and 13C show the comparison between the three phase actual currents and the three phase reference currents, according to the control system 60 and the control method of the invention and using an inadequate value of leakage induction 0.5 L_σ . Fig. 12A shows A phase reference current $I_{a5,refer}$, Fig. 12B shows A phase actual current $I_{a5,actual}$, Fig. 13A shows a comparison between A phase reference current $I_{a5,refer}$ and A phase actual current $I_{a5,actual}$, Fig. 13B shows a comparison between B phase reference current $I_{b5,refer}$ and B phase actual current $I_{b5,actual}$, and Fig. 13C shows a comparison between C phase

reference current $I_{c5,refer}$ and C phase actual current $I_{c5,actual}$. As shown in Figs. 13A, 13B and 13C, even using the inadequate leakage induction 0.5 L_σ, three phase actual currents $I_{a5,actual}$, $I_{b5,actual}$, $I_{c5,actual}$ are still almost equal to the three phase reference currents $I_{a5,refer}$, $I_{b5,refer}$, $I_{c5,refer}$, respectively.

Therefore, as shown in Fig. 8A to Fig. 13C, within ±50% error of the leakage inductance L_σ, the three phase actual currents can be almost equal to the three phase reference currents. The control method of the invention not only preserves the merit of constant switching frequency of the conventional PI-PWM control system, but also can eliminate the motor current phase-lag problem of the conventional PI-PWM control system. Also, the control method of the invention will have the following characteristics and economic advantages such as high accuracy, fast response, low cost and robustness etc.

In the above embodiments, the leakage inductance L_σ is the only variable. The leakage inductance L_σ is determined usually by the parameter test of the motor. If the parameter test is not correct, the value of the leakage inductance L_σ may be above the correct value in the error ±50%. If the incorrect leakage inductance L_σ with above ±50% error is utilized to calculate the d-axis voltage V_{ds} and the q-axis voltage V_{qs}, the three phase actual currents may be not equal to the three phase reference currents. Therefore, the leakage inductance L_σ must be real-time auto-tuning as follows.

At a sample period, Equations (6) and (7) are modified as follows.

$$V_{ds1} = L_\sigma \frac{di_{ds1}}{dt} - L_\sigma \omega_e i_{qs1} + E_{ds1} = m_{d1} L_\sigma + E_{ds1} \qquad (17)$$

$$V_{qs1} = L_\sigma \frac{di_{qs1}}{dt} + L_\sigma \omega_e i_{ds1} + E_{qs1} = m_{q1} L_\sigma + E_{qs1} \qquad (18)$$

Wherein in Equations (17) and (18) the variables are the leakage inductance L_σ , E_{ds1} and E_{qs1} , the m_{d1} and m_{q1} are defined and obtained as follows $m_{d1} = (\frac{di_{ds1}}{dt} - \omega_e i_{qs1})$. $m_{q1} = (\frac{di_{qs1}}{dt} + \omega_e i_{ds1})$.

At a next sample period, Equations (6) and (7) are modified as follows.

$$V_{ds2} = L_\sigma \frac{di_{ds2}}{dt} - L_\sigma \omega_e i_{qs2} + E_{ds2} = m_{d2} L_\sigma + E_{ds2} \qquad (19)$$

$$V_{qs2} = L_\sigma \frac{di_{qs2}}{dt} + L_\sigma \omega_e i_{ds2} + E_{qs2} = m_{q2} L_\sigma + E_{qs2} \qquad (20)$$

Wherein in Equations (19) and (20) the variables are the leakage inductance L_σ , E_{ds2} and E_{qs2} , the m_{d2} and m_{q2} are defined and obtained as follows $m_{d2} = (\frac{di_{ds2}}{dt} - \omega_e i_{qs2})$. $m_{q2} = (\frac{di_{qs2}}{dt} + \omega_e i_{ds2})$.

Equation (19) minus Equation (17) is as follows.

$$(V_{ds2} - V_{ds1}) = (m_{d2} - m_{d1})L_\sigma + (E_{ds2} - E_{ds1}) \cong (m_{d2} - m_{d1})L_\sigma \qquad (21)$$

In Equation (21), because the sample time is very small, the difference between the E_{ds2} and E_{ds1} can be ignored so that $E_{ds2} \cong E_{ds1}$. Therefore, the leakage inductance $L_{\sigma,d}$ is estimated using d-axis Equations (17) and (19). The expression of the leakage inductance $L_{\sigma,d}$ is as follows.

$$L_{\sigma,d} = (V_{ds2} - V_{ds1})/(m_{d2} - m_{d1}) \qquad (22)$$

Similarly, Equation (20) minus Equation (18), and the difference between the E_{qs2} and E_{qs1} can be ignored. The leakage inductance $L_{\sigma,q}$ is estimated using q-axis Equations (18) and (20). The expression of the leakage inductance $L_{\sigma,q}$ is as follows.

$$L_{\sigma,q} = (V_{qs2} - V_{qs1})/(m_{q2} - m_{q1}) \quad (23)$$

Therefore, the leakage inductance L_σ is defined as an average of the leakage inductance $L_{\sigma,d}$ and the leakage inductance $L_{\sigma,q}$ as follows.

$$L_\sigma = 0.5 * (L_{\sigma,d} + L_{\sigma,q}) \quad (24)$$

The leakage inductance L_σ is calculated by the above Equations (17) to (24). The calculated leakage inductance L_σ is inputted to Equations (6), (7), (10) and (11) to calculate V_{ds} , V_{qs} , E_{ds} and E_{qs} for two sample periods as V_{ds1} , V_{qs1} , V_{ds2} and V_{qs2} . Therefore, the value of V_{ds1} , V_{qs1} , V_{ds2} and V_{qs2} in Equations (17), (18), (19) and (20) can be obtained to calculated a new leakage inductance L_σ . Every two sample periods , the leakage inductance L_σ is calculated and updated to input to Equations (6), (7), (10) and (11) to calculate V_{ds} , V_{qs} , E_{ds} and E_{qs} . Therefore, Equations (17) to (24) is calculated every two sample periods to obtained a new leakage inductance L_σ so that the leakage inductance L_σ can approach the correct value.

Referring to Fig. 14A to Fig. 14D, it shows a simulation using the Matlab software. As shown in Fig. 14D, the leakage inductance L_σ can approach to the correct value and be stable within 0.25 second.

Referring to Fig. 6B, the micro-programming & memory controller 61 further comprises an fourth calculating means 617 for estimating the leakage inductance L_σ according to the above method. Therefore, by using the estimation of the leakage inductance L_σ the control system 60 can improve the robustness.

While an embodiment of the present invention has been illustrated and described, various modifications and improvements can be made by those skilled in the art. The embodiment of the present invention is

therefore described in an illustrative but not restrictive sense. It is intended that the present invention may not be limited to the particular forms as illustrated, and that all modifications which maintain the spirit and scope of the present invention are within the scope as defined in the appended claims.